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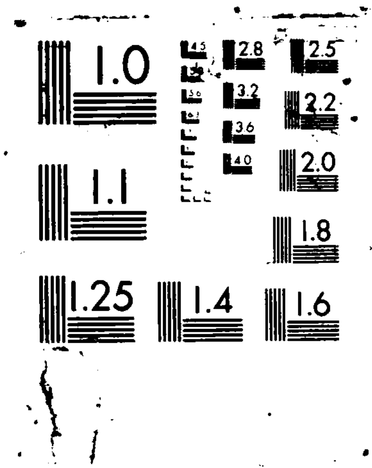
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PULSED SPRAY STRUCTURE AND ATOMISATION TECHNIQUES

by

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August 1987

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The process of atomisation from diesel injectors is found to persist for a significant proportion of the spray length before impaction on the cylinder wall. Both aerodynamic shear and cavitation appear to be of importance for the liquid jet breakdown. In addition cyclic variations are found in the atomisation and penetration of sprays. The transient nature of the spray initial conditions can cause pile up and coagulation of droplets at the leading edge of the spray pulse for certain cases. Improved modeling of diesel injection requires recognition of these phenomena and this is supported by both modeling and experimental data which have been obtained under realistic engine conditions in a specially developed rig.

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ABSTRACT

The process of atomisation from diesel injectors is found to persist for a significant proportion of the spray length before impaction on the cylinder wall. Both aerodynamic shear and cavitation appear to be of importance for the liquid jet breakdown. In addition cyclic variations are found in the atomisation and penetration of sprays. The transient nature of the spray initial conditions can cause pile up and coagulation of droplets at the leading edge of the spray pulse for certain cases. Improved modeling of diesel injection requires recognition of these phenomena and this is supported by both modeling and experimental data which have been obtained under realistic engine conditions in a specially developed rig.

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SUMMARY

This report describes a 36 month research project which had the objective of deriving fundamental information on the structures of pulsed liquid sprays as they penetrate, vaporize, and mix in a gas stream. The information derived has useful applications in the area of the design of direct injection diesel engines and in particular, small high speed engines or engines running off poorer grades of fuel. The report presents an outline of the salient features of the investigation and for more detailed information reference should be made to the several theses, dissertations and papers which have been prepared as a result of the investigation.

The investigation is divided into 4 principal features which are in order of the effort expended:

1. The development and use of a high pressure wind tunnel to investigate the structure and behaviour of sprays from real diesel injectors.

2. Comparison of the spray data with computations using a computer model which was specially modified for this purpose.

3. The investigation of the initial atomisation process by the use of scaled up models of diesel injectors.

4. Investigation of the use of non-standard atomiser designs to replace the standard diesel injectors.

Sprays were investigated in the wind tunnel for various injection conditions, for different orientation of injector with respect to a crossflow and for different gas pressures and temperatures. Particular attention was paid to the accurate measurement of initial conditions at the injector. Photographs and movie films were analysed by computer techniques. Penetration data compared generally well with measurements. The principal disagreement was found to be due to the gradual atomisation process which was observed in the sprays: The liquid column leaving the injector nozzle remains relatively intact for an important proportion of the spray length and this effect must be included in the computer model. Novel measurement techniques applied in the sprtays included the use of capacitance probes to detect spray density and the use of a single beam laser interferometer to detect droplet velocity.

The large scale model experiments were in reasonable agreement with the observed gradual breakdown of the liquid column. This process was initiated with surface waves on the column near the injector which leads to a shearing-off of fluid lumps from the edge of the column. At the same time there are internal disturbances within the column which are attributed to cavitation bubbles. Experiments were conducted with different atomisation techniques including air assisted atomisation, swirl jet atomisation and impinging jet atomisation. Swirl jet atomisation was found to be poor for direct injection due to the poor penetration. Air assisted atomisation produced reasonable results but suffers due to the complexity of the atomiser design. Impinging jet atomisation is promising from the point of view of obtaining good penetration at the same time as obtaining good atomisation. However further development work is required to develop a suitable impinging jet injector design.

1 INTRODUCTION AND OBJECTIVES

There is little reliable data on the structures of the pulsed sprays used for diesel engines particularly for cases in which the initial and boundary conditions of the spray are carefully measured and also varied systematically.

Computer models of in-cylinder characteristics of direct Injection (DI) engines require experimental information of this type to aid their development and to test their accuracy. Furthermore there has been little serious effort, in modern times, to investigate the usefulness of atomisation techniques, for DI engines, other than the simple pressure jet injectors which are now used universally. The present experimental study commenced with two objectives, with the former being the pincipal objective:

(1) To provide accurate data on the various important parameters of diesel spray structure for carefully measured and systematically varied initial and boundary conditions and for realistic injector/pump combinations.

(3) To examine injection using modified injection techniques to see whether improvements in mixing, ignition delay, penetration , pollutant emissions etc. can be made.

In addition during the initial stages of the work it became clear that two further broad objectives must be addressed. One of these refers to the development and application of specialised measurement techniques and the other refers to the modification and application of a computer model to predict the flows which were investigated. Regarding measurement techniques, diesel sprays have peculiarities which make their investigation exceptionally difficult. Principally these difficulties include their extremely high density in the zone of interest and their transient natures. These difficulties make the development and refinement of measurement and data analysis techniques an essential part of the investigation. Furthermore it is of importance that the initial breakup of the liquid jet emerging from the injector nozzle is characterised in some way and eventually modelled. this has been suspected in the past and confirmed by the initial stages of this investigation. In most atomisation systems this zone is not of importance but for diesel sprays it can occupy an appreciable proportion of the spray length before impaction. To aid this understanding of the liquid column break up a novel technique of large scale experimental modeling was evolved. Effectively this resulted in the construction of a large scale model of a diesel injector nozzle and valve and the use of a fluid and flow rate such that important non dimensional parameters such as Reynolds number and Weber number truly reflected those in the real scale injectors.

During the course of the investigation a three dimensional two phase, time stepping computer model became available and it was clear that this could be modified to be applied to predict the

various flows which were being measured. Such a modification became part of the research effort and as information on initial conditions became available these were supplied to the computer model so that direct comparisons of prediction and measurement could be made. It is emphasised that these comparisons are, as far as is known, unique, being the only direct comparison of measurement and "theory" under realistic conditions and with realistic injectors/pumps with accurately measured time dependent intial conditions. These results were made possible by the development of a new concept in the investigation of diesel sprays by the use of a specially designed wind tunnel. This was a high gas pressure closed circuit wind tunnel which allows sprays to be investigated, with excellent optical access, and realistic pressures, temperatures and gas velocities.

In this report detailed consideration will not be made of previous work on the subject of diesel sprays and reference should be made to the papers and theses originating from this work for more information. However, in brief, the sprays from single hole nozzles, which are of principal interest here, were first investigated in detail in NACA work in the 1920's by using photography and the collection of droplets far downstream in an oil bath. These basic techniques have remained the mainstays of diesel spray injection investigations since that time and the main body of work has originated in Japan were many investigations of diesel spray penetration and droplet sizes have ben made. The principal criticisms of this body of work include:

(1) Initial conditions at the injector are either not measured accurately or else the injection technique does not truly reflect those found in practice.

(2) Immediate atomisation, on leaving the nozzle, was assumed so that the measured droplets, found far downstream, were assumed to represent what one finds in the near nozzle zone.

Recently, in parallel with the results of the present investigation, it has been suggested that the latter supposition is quite incorrect and the real injectors have a significant breakup length. As modern computational fluid dynamics computer models have developed in recent years it has become obvious that the existing data base is quite poor and unreliable and that there is an almost complete absence of data for situations such as a pulsed spray in a gas crossflow.

Recently a resurgence of interest has grown in diesel engines which has been driven by several factors including the desire for optimum fuel economy, the requirements for low emissions and the requirement to use a wider range of liquid fuels. This is particularly so for the cases of smaller/medium size engines as used in trucks and, increasingly, in private automobiles. For the latter there is a particular interest in overcoming the current problems in using direct injection techniques in small engine cylinders. A quite separate factor which encourages the derivation of more information on diesel injection is the use of ceramic cylinder heads for so called adiabatic engines. in this

situation, were hot spots must be minimised, it is clearly important to avoid direct flame impaction.

2 OVERVIEW OF THE EXPERIMENTAL PROGRAM

The main measurement program has been concerned with the study of sprays produced by commercial single hole injectors supplied by fuel from appropriate rotary or plunger type fuel pumps. The injectors chosen are similar to those employed in the smaller or medium sized diesel engines with hole diameters in the range 0.2mm to 0.5mm. In the experimental programme the main interest has been in the interaction of the spray with the gas flow, in the atomisation process and in vaporisation leading to the ignition conditions. Thus measurements have not been made in burning sprays but rather in sprays in conditions of gas temperature, velocity and pressure which reflect those found in the engine cylinder prior to ignition. An initial feature of the work was the commissioning of a new high pressure wind tunnel rig for the principal measurement program. A separate rig was constructed for the large scale injector modeling investigation and tests on novel injection techniques were carried out initially at atmospheric conditions with subsequent use of the modified injector in a Petter single cylinder engine. Much of the research work, including the development of improved measuremnt techniques, was carried out in parallel with several personnel working as a research team. Unless otherwise stated all of the measurements in this research study made use of standard UK diesel oil (DERV).

It is emphasised that this report presents an outline of the research with specimen results. Reference should be made to the papers and theses listed at the end of the report for further information or direct contact should be made with the principal investigator.

3 THE APPARATUS AND MEASUREMENT TECHNIQUES

3.1 HIGH PRESSURE WIND TUNNEL

A rig was required in which pulsed sprays may be examined in environments which model those found within engine cylinders. However as the atomisation, penetration and vaporisation processes are of principal interest the rig must model these conditions without the occurrence of ignition and combustion. The rig was to be a simplified version of the engine situation which had optimum optical and probe access and which would permit accurate measurement of initial and boundary conditions.

The closed circuit high pressure/high temperature wind tunnel which was developed and constructed is shown in Fig.1. This permits injection of a spray from the roof of the working section which was 70mm high by 120mm wide. The spray could be injected into either ambient conditions or into a cross flow of gas. The gas temperature could be up to 50bar and the gas temperature could be up to 800K. The velocity could be varied up to 15m/s and the turbulence level could also be varied although this was not achieved within the present experimental program. Large quartz windows at the side of the working section permit high speed photography of the sprays and also the use of laser diagnostics. The wind tunnel was fully self contained and it was usually pressurised by using carbon dioxide gas so that ignition did not occur. The use of carbon dioxide allowed the use of high equivalent air pressures due to its relatively high molecular weight. The tunnel could be transported to different laboratories and this was the case, for example, when making laser inteferometer measurements when the rig had to be moved to the specialised instrument laboratory.

All measurements must be synchronised with respect to the position of the needle valve in the injector in use. This is achieved by the use of a specially developed need lift detector system which could be installed on each injector. In addition a fuel line pressure transducer sytem was developed which used strain gauges.

3.2 THE LARGE SCALE MODELS

Figure 2 shows one of the two large scale models of a diesel injector which were constructed. These had scale up factors 20x and 40x. The injector nozzle was supplied from a pressurised reservoir containing the liquid which represented the fuel. This liquid was a mixture of glycerene and water in a ratio such that the resulting surface tension, viscosity and density permitted the attainment of Reynolds and Weber numbers for the flow, leaving the nozzle, which were very similar to those found for a

true scale injector in an engine. This takes into account that the large scale model injects into atmospheric conditions while the small injector injects into the high pressure and temperature gas. Full details of the design and analysis are given in the Thesis of Giamuzis (1987) and will be reported in a technical paper in preparation. The flow from the large scale model was started by rapidly lifting the large scale needle valve by using a solenoid. The signal activating the solenoid was also used to activate the time delay electronics which were used to trigger photographs of the resulting spray.

3.3 THE MEASUREMENT TECHNIQUES: PHOTOGRAPHIC

A high speed Hadland movie camera was used with a maximum framing rate of 11000 pps. This was generally used in the shadowgraph mode with back-lighting of the spray emeging from the injector. Typically 8 pulses could be analysed from a film when the pump was running at the usual speed of 1500rpm which was used in the tests.

A spark photographoc system was also employed in the tests. This used a "4x5" technical camera with a Polaroid film holder. The magnification was varied between 3x and 20x accordinbg to the requirements of the investigation. This was also used in a shadowgraph mode but now the spray light source was collimated and focused at the lens of the camera. The light source is triggered by a time delay circuit which is synchronised with respect to the commencement of needle lift.

In most cases spray density and atomisation quality was such that few droplets could be observed on photographs. Some tests were conducted which attempted to penetrate the dense spray zones by either using optical guide tubes or by removing a small slice of the spray by using to adjacent knife edges. These techniques met with varying success and suffered from the problems introduced by interfering with the flow.

The principal data obtained from the photographs were spray boundary, deflection and penetration as a function of time. Movie films and photographs were analysed initially either manually or by a film analyser system. At a later stage a method was developed for inputting data directly into microcomputers. The application of this technique was developed and reported by Aspiotis (1987). Photographs are placed onto a digitiser tablet and both the outer spray boundary and the inner dense core boundary, visible in many situations, are traced. The microcomputer stores the information from several photographs or movie film stills and then computes the required information such as spray angle, penetration versus time and spray deviation. The system may also be used to store information from several photographs taken at the same time after injection for different spray pulses and thus obtain information on averaged structure

and cyclic variations.

A technique for more rapidly measuring penetration was developed during the measurements. In this technique the shadow image of the spray was projected onto a small photodiode and when the diode signal started to drop it was assumed that the leading edge of the spray was passing.

3.4 MEASUREMENT TECHNIQUES: PROBES

The types of probes usable in these dense transient sprays were found to be severly restricted in number and eventually only two physical probes were found to give any useful results:

A Patternation Probe is designed similar to a pitot tube but at a chamber near its tip there is a small piezoelectric transducer. The signal provides information on the instantaneous total local momentum flux in the spray and frequency response, up to 100 kHz, is adequate for typical sprays.

A Capacitance Probe was specially developed for this work. as shown in Figure 3. The probe body supports two small parallel brass plates in the spray in such a way that the spray passes between the plates relatively undisturbed. The instantaneous capitance between the plates is related to the average concentration of liquid in this zone so that the technique is a fast response method for detecting the instantaneous spray density in terms of liquid phase/gas phase. The capacitance is measured by a fast response tuned oscillator circuit.

Standard probes were used for measurements in the gas outside the sprays including pitot tubes, hot wire anemometry and thermocouples.

3.5 LASER DOPPLER INTERFEROMETER

A relatively new type of sing'; beam laser system was applied to the sprays to measure liquid phase velocity as a function of time and position. Details of this technique are given in the attached paper, Yule et al (1987), and will also be reported in the thesis of Aval (1987). In brief the technique is much less sensitive to the problems of multiple scattering for dense sprays than are standard techniques and it also has an extremely fast frequency response being capable of measuring velocity fluctuations at frequencies up to 1MHz.

3.6 DATA ACQUISITION AND PROCESSING

Needle lift, fuel pressure, diode, capacitance probe and patternation probe signals were acquired either by a multichannel transient recorder or be a DEC PDP11 laboratory microcomputer system. The Laser Interferometer signals were acquired by a transient recorder and then dumped into a Commodore PET computer for further analysis.

4 SAMPLE EXPERIMENTAL RESULTS

Figures 4 and 5 show spray penetration data as a function of time after injection for two different nozzles. Figure 6 shows spray angle data. A range of cyclic variation is shown in Figure 4 and this was typical for all injectors examined. It is found that spray penetration is mainly dependent on gas density and only weakly dependent on gas temperature.

Figures 7 and 8 compare measured penetration with the model predictions. The area of poor agreement is generally within the first 50 nozzle diameters and, from the photographs and capacitance probe data, this coincides with the zone of incomplete atomisation. It is clear that the model requires some type of submodel which describes the gradual breakdown of the liquid column.

Figures 9 and 10 show data for sprays in cross flows and in these conditions it was noted that the poorly atomised dense core zone was more clearly revealed by the blowing away of the sheath of droplets.

Figure 11 shows a case were the injector is orientated at an angle of 45 o with respect to the, now, coflowing gas stream.

In order that these measurements are useful it is essential that the initial time dependent conditions at the nozzle orifice are known. These are computed from the measured fuel pressure and needle lift signals coupled with measurements of nozzle discharge coefficients as a function of these two parameters which were obtained at static rather than dynamic conditions. Figure 12 shows such an initial condition obtained for one of the three injectors which were used. These measurements were independently correlated with the laser and patternation probe data with good agreement.

Figure 13 shows capacitance probe measurements and the decrease in spray density with distance downstream is evident.

Figure 14 shows laser interferometer data within one of the sprays. These represent the first velocity measurements which have been made within a diesel spray in the principal zone of interest near the nozzle. The change in velocity signature with distance downstream agrees quite well with what is predicted by the computer model.

All of these various pieces of information may be combined in different ways and further useful information may then be extracted. As an example Figure 15 shows data on the local void fraction as a function of downstream distance, see Tham (1987). Data such as these may be further analysed to provide information on spray breakup length. Figure 16 shows such information where the dependency of spray breakup length on gas pressure is seen.

Turning to the large scale model experiments Figure 17 shows droplet size data obtained from the scaled up sprays: Rather surprisingly there does seem to be a reasonable scaling up of droplet sizes in spite of the presence of non-linear effects at later stages of the breakup process which one not expect to simply scale up. It was found that caviatation bubbles could be seen withtin the nozzle and that these were correlated with the initial perturbations of the surface of the liquid column as it emerged from the orifice. Figure 18 shows a typical engine test using a specially constructed impinging jet injector. Clearly further work is required to release the full potential of this technique. The impinging jet design was found to be superior to the swirl jet and air assisted atomisation techniques for the diesel application.

5. CONCLUDING REMARKS

This wide ranging experimental investigation has provided a very large volume of new data on diesel spray structure and behaviour under carefully controlled and measured conditions. The usefulness of the data base has already been proved by the validation and improvement of the in-house computer model at UMIST which is used to predict in-cylinder flows. The ancillary inestigations of scaled up sprays and novel injection techniques are preliminary in nature but the results are sufficiently interesting to encourage further investigation of these techniques. At the time of writing the experimental and data processing program which commenced with this contract is continuing: The wide range of possible parameter variations and requirements specified by computer modeling groups provides an almost open ended experimental plan for the basic wind tunnel rig.

6. REFERENCES

Aspiotis, A. "Analysis of diesel spray photographs by microcomputer", MSc dissertation, Dept Mech. Eng., UMIST, 1987.

Aval, S.M. "Studies of diesel sprays in cross flows", PhD thesis to be submitted to UMIST, 1987.

Giamuzis, A. "Large scale modelling of diesel injectors", MSc Thesis, Dept Mech. Eng. UMIST, June 1987.

Tham, S.Y. "The study of diesel spray structure and penetration in a high pressure and temperature gas", PhD Thesis, Dept Mech. Eng., UMIST, June 1986.

Yule, A.J. and Aval, S.M. "A technique for velocity measurements in diesel sprays" Submitted to Atom. and Spray Tech., 1987.

Yule, A.J., Mo, S.L., Tham, S.Y. and Aval, S.M. "Diesel spray structure" Proceedings of ICLASS-85, Editors A.J.Yule and P.Eisenklam, Inst Energy, London, 1985.

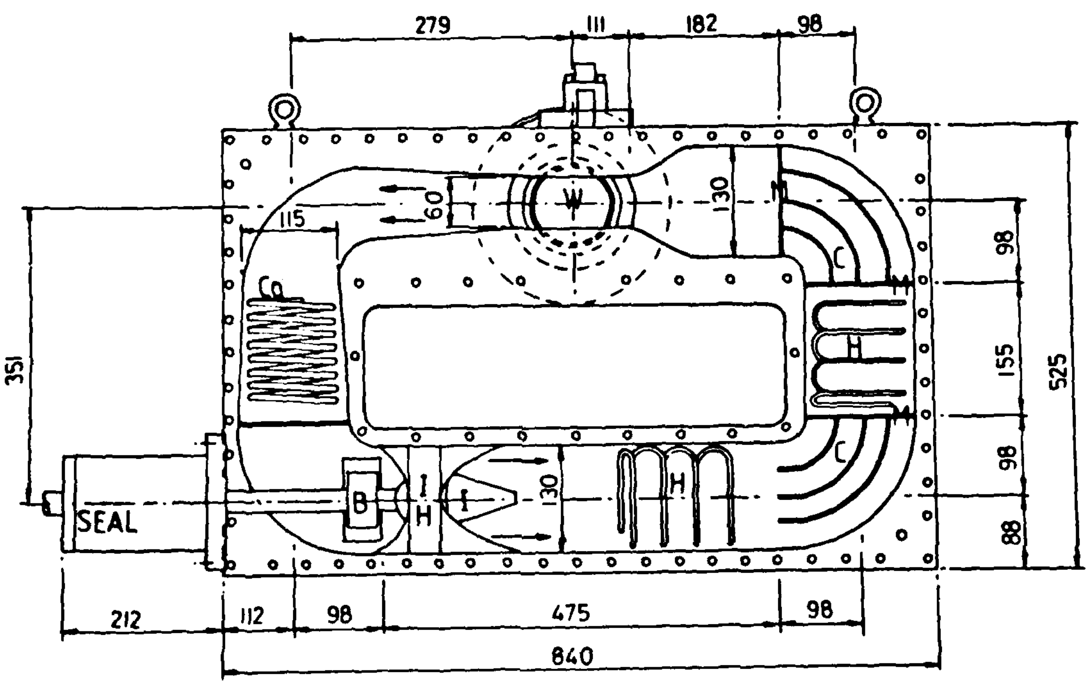


Figure 1. Cross Section View of The High Pressure/High Temperature Wind Tunnel

B_Bearing C_Corner Vanes Co_Condenser
H_Heating Element I_Impeller I.H_Impeller Housing
W_Quartz Windows M_Wire Mesh

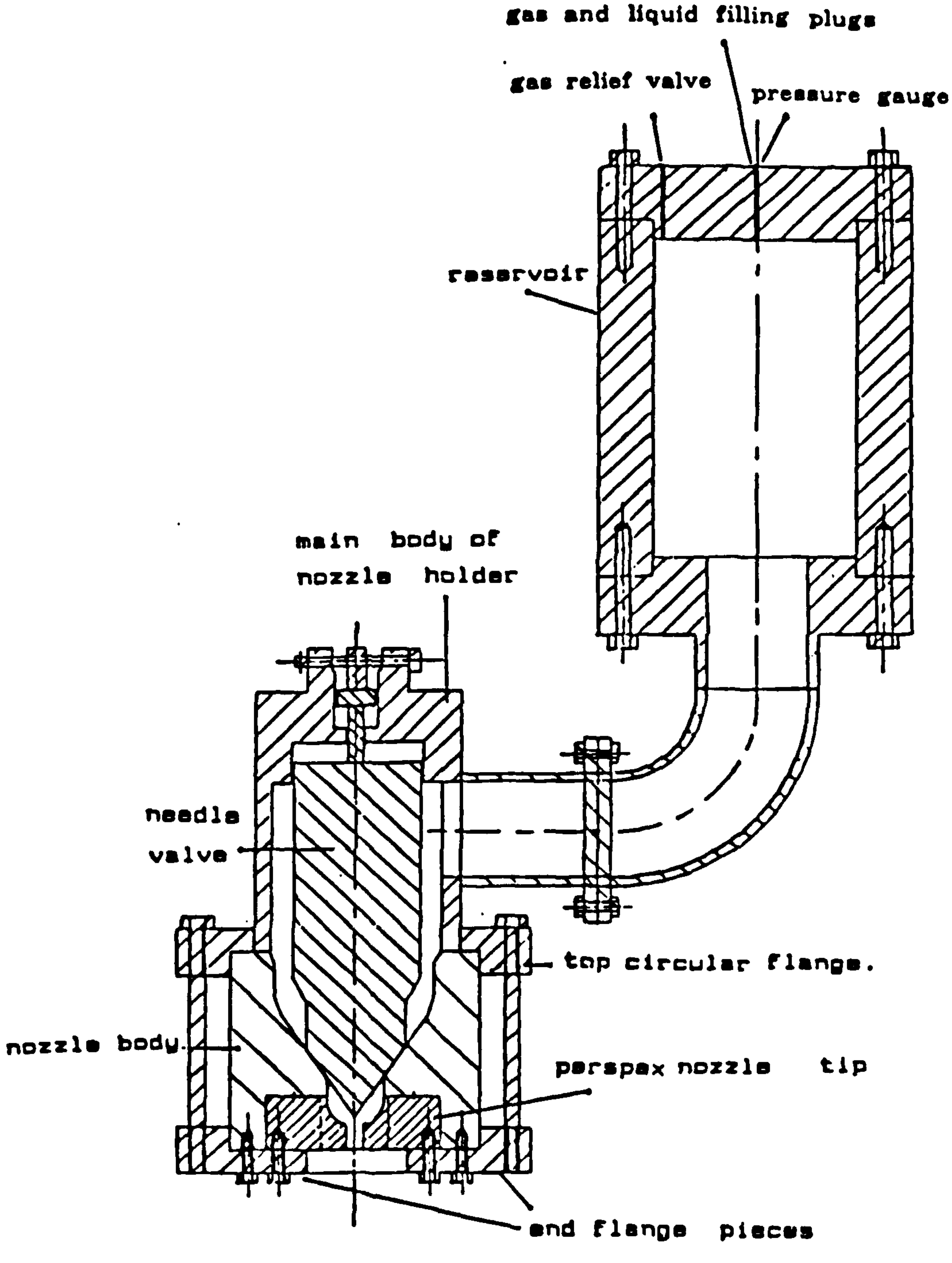


Figure 2 Assembly drawing of 12 mm nozzle apparatus.

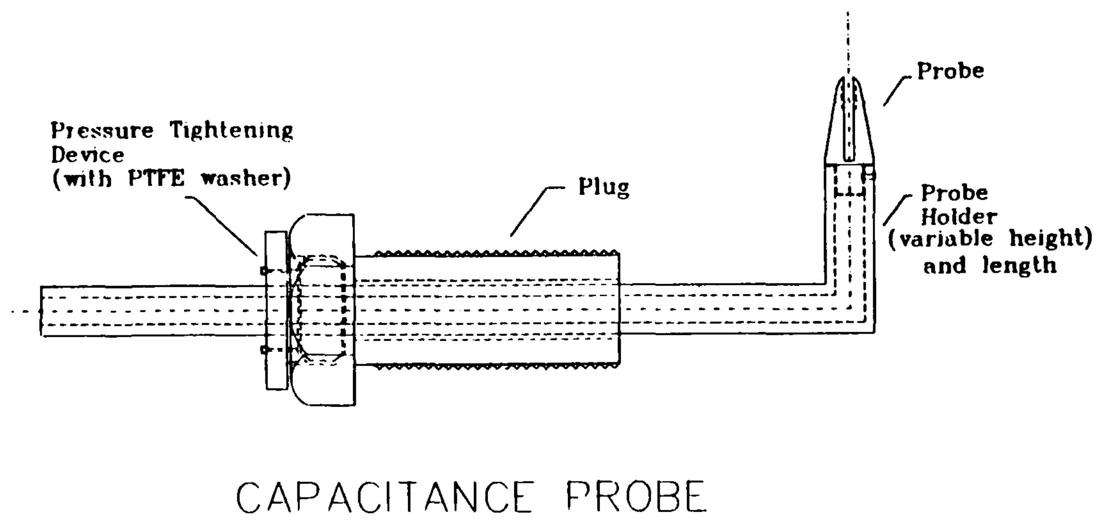


Figure 3. Capacitance probe for spray density measurement

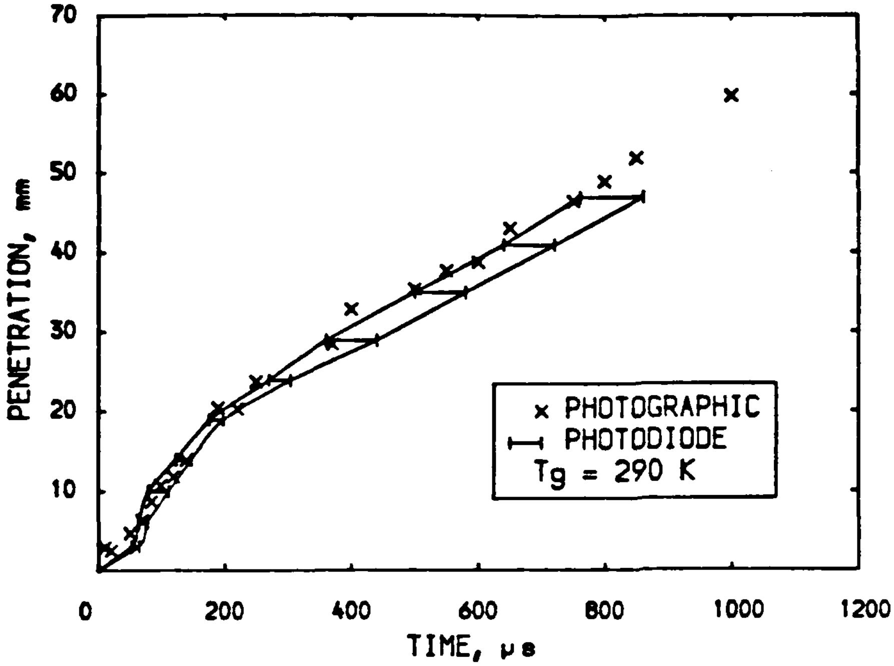


FIG. 4 (i) PENETRATION RATE USING TWO TECHNIQUES FOR 0.46 mm NOZZLE, P_g = 45 bar

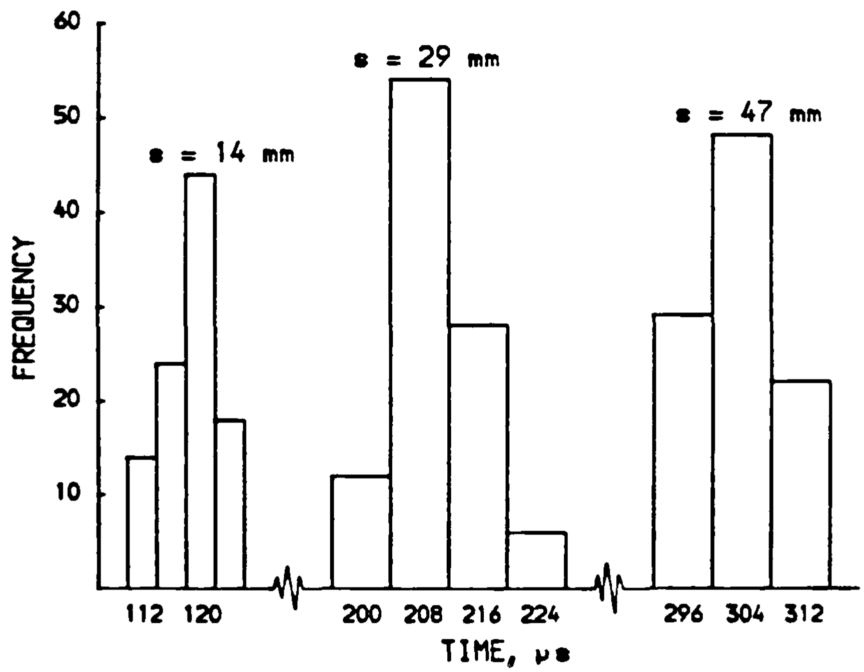


FIG. 4(ii) HISTOGRAMS OF PENETRATION TIME FOR 0.46 mm NOZZLE, P_g = 5 bar, T_g = 290 K

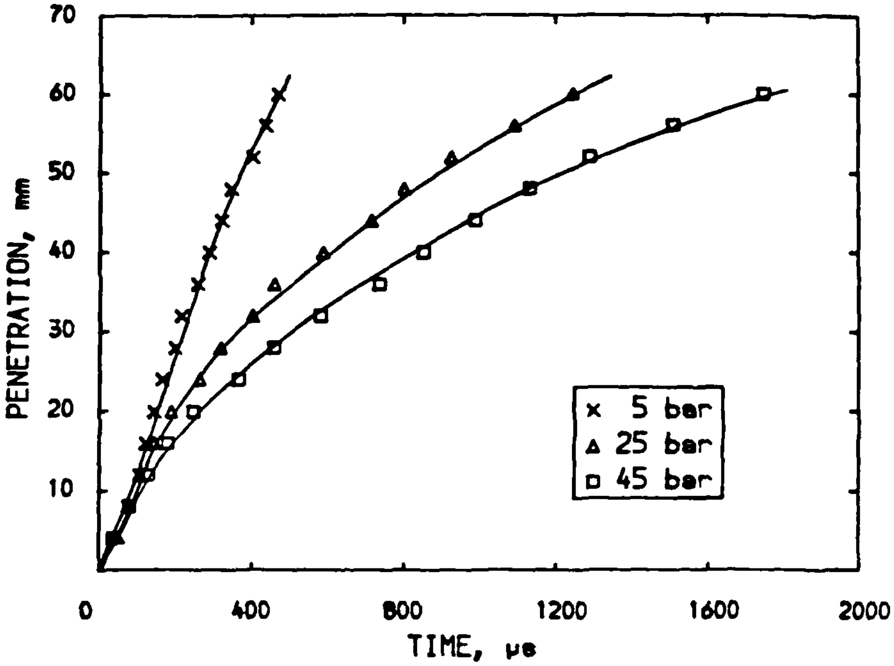


FIG. 5 (i) EFFECT OF GAS PRESSURE ON PENETRATION RATE FOR 0.213 mm NOZZLE, Tg = 573 K

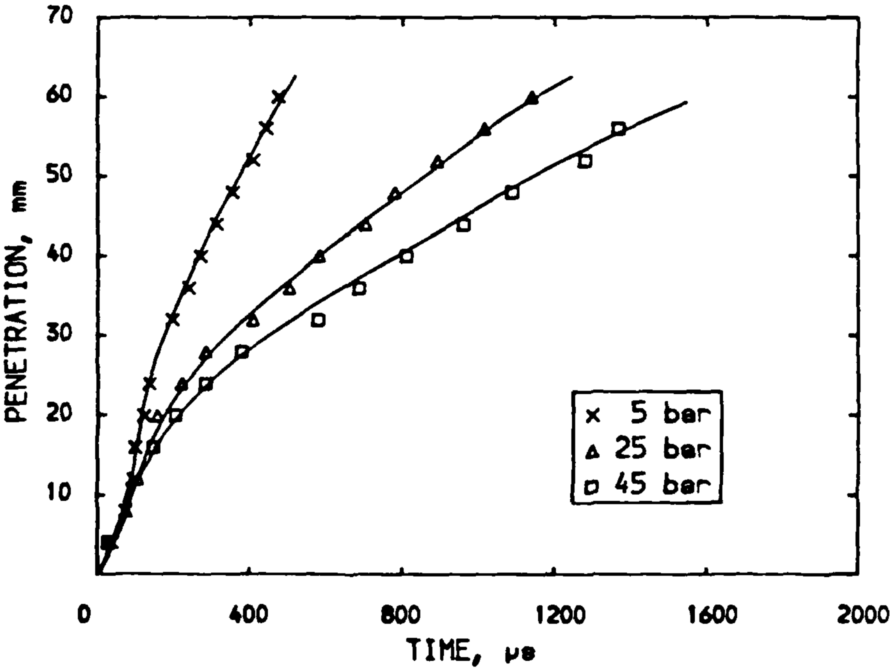


FIG. 5 (ii) EFFECT OF GAS PRESSURE ON PENETRATION RATE FOR 0.213 mm NOZZLE, Tg = 673 K

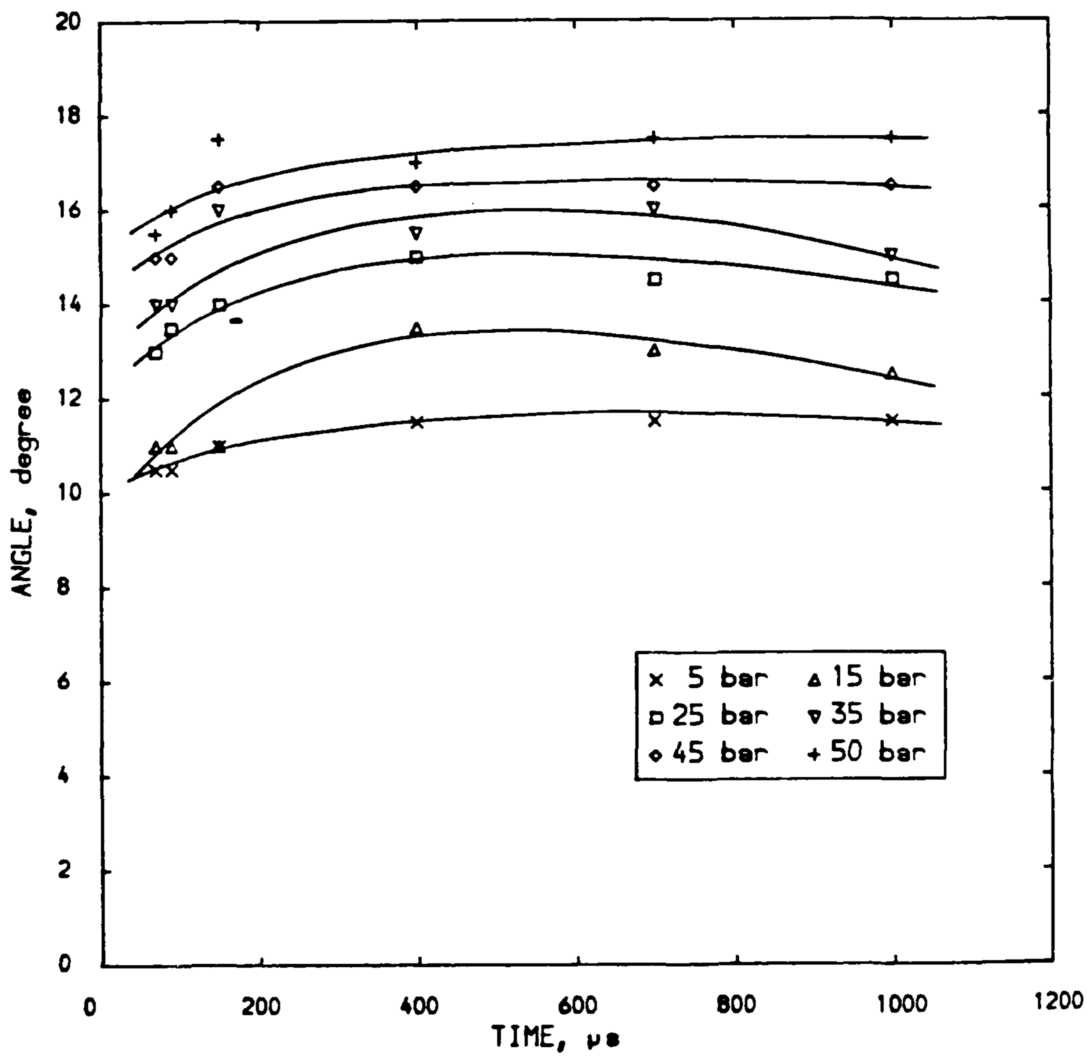


FIG. 6. EFFECT OF GAS PRESSURE ON CONE ANGLE FOR 0.46 mm NOZZLE, Tg = 290 K

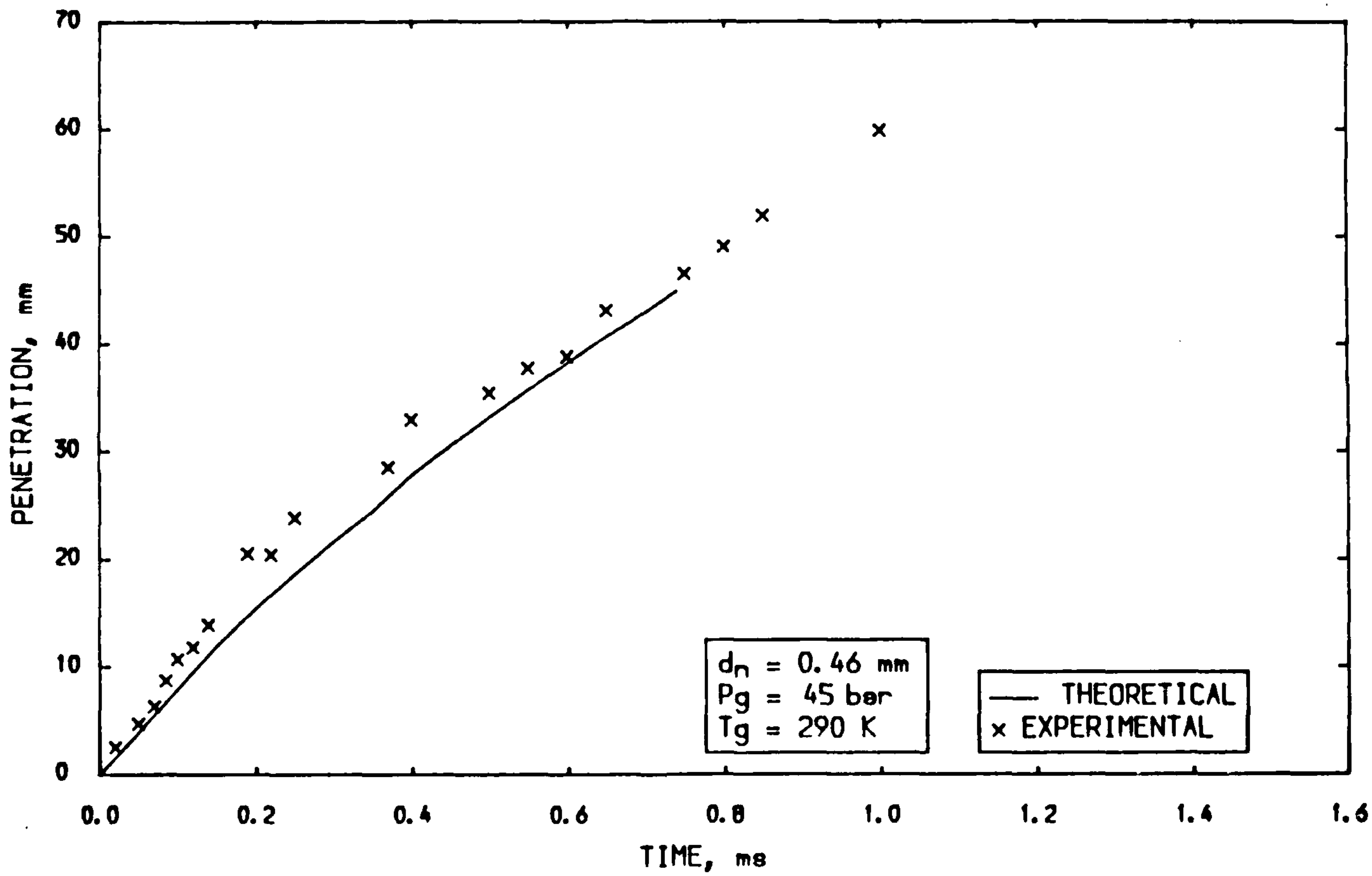


FIG. 7. COMPARISON BETWEEN THEORETICAL (BASED ON TURBULENCE SPRAY MODELLING) AND EXPERIMENTAL PENETRATION

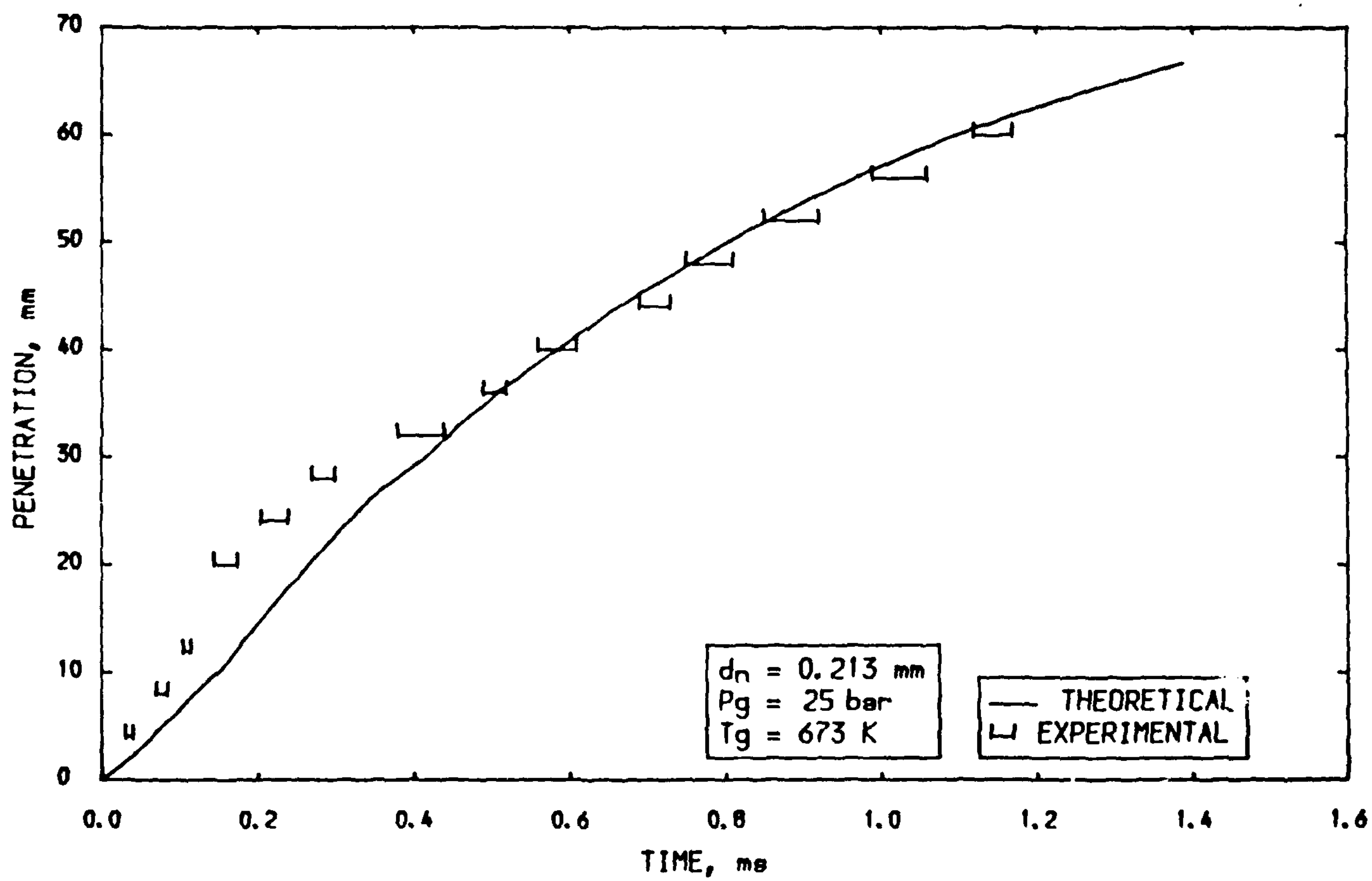


FIG. 8. COMPARISON BETWEEN THEORETICAL (BASED ON TURBULENCE SPRAY MODELLING) AND EXPERIMENTAL PENETRATION

Figure 9. Example of spray boundary as function of time in crossflow

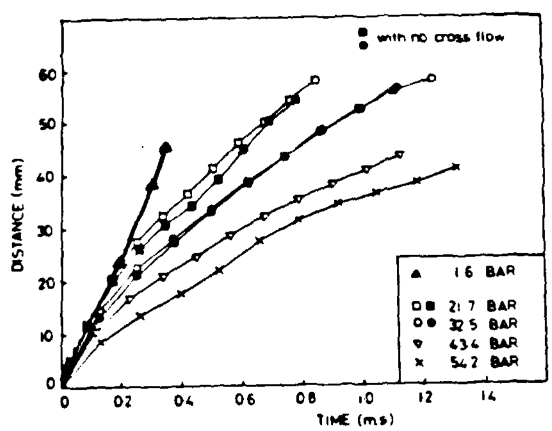


Figure 10. Spray penetration in a crossflow

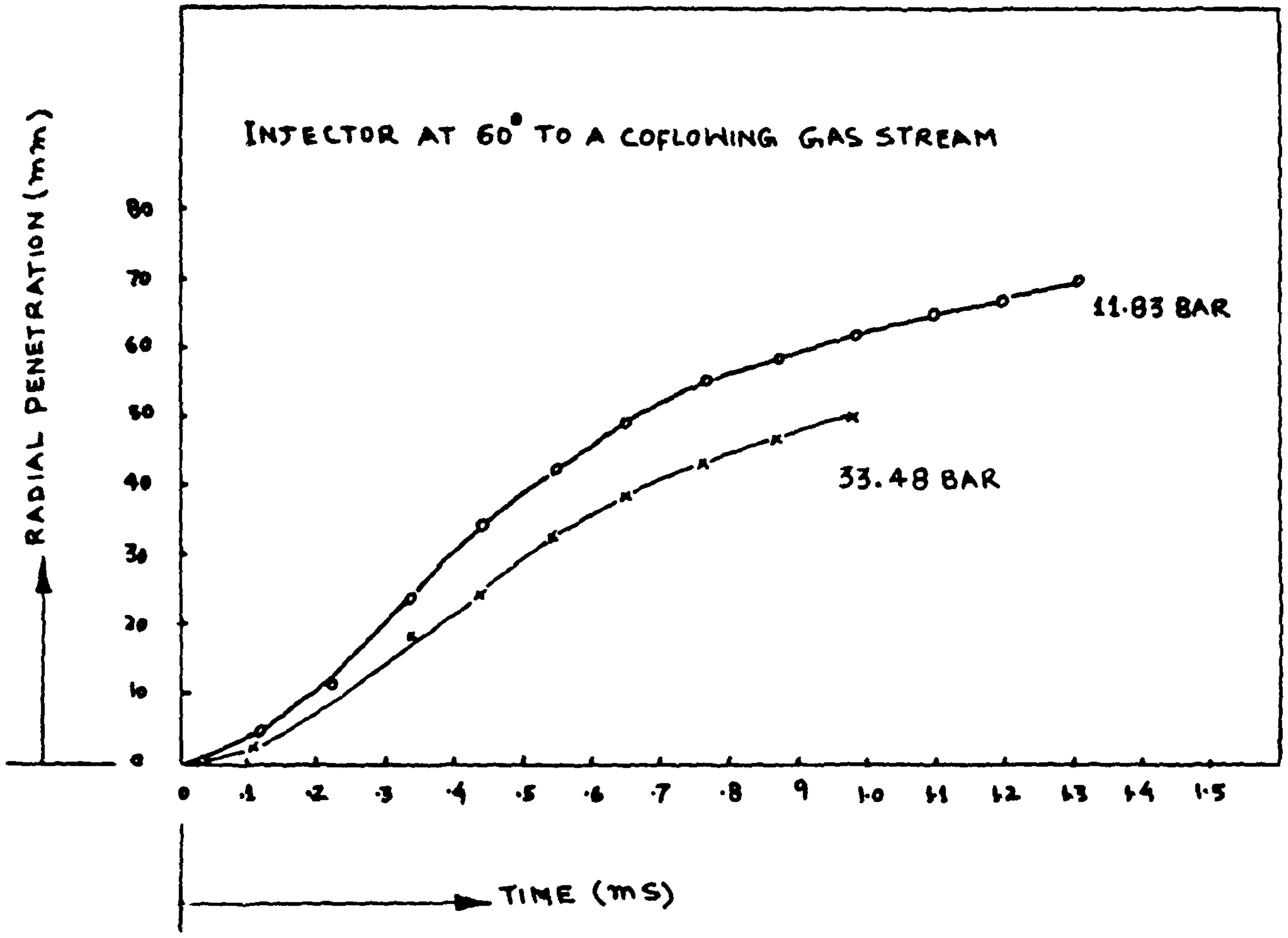
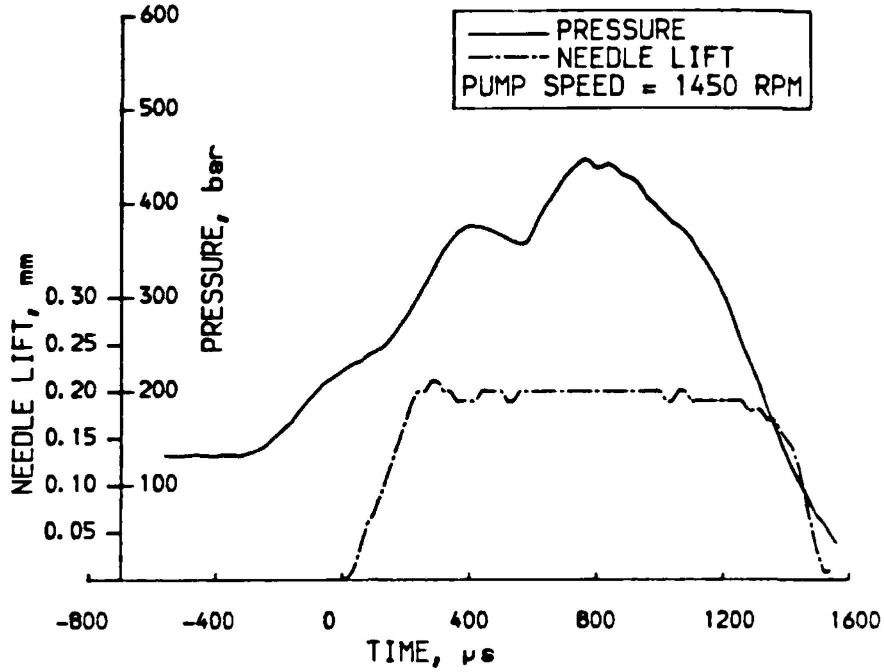


Figure 11. Spray penetration with crossflow at 60° to nozzle axis



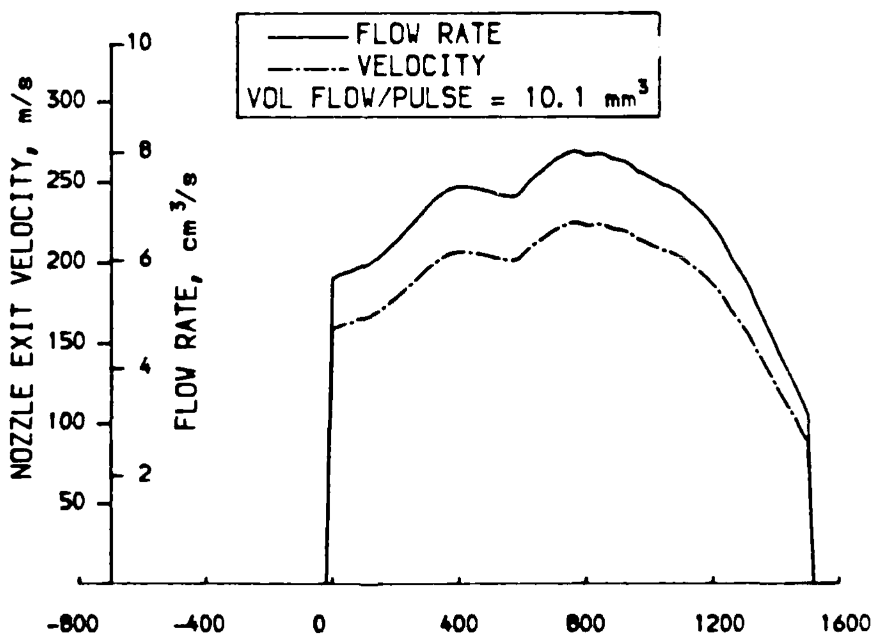


FIG. 12. FULL RACK FUEL DELIVERY CURVES AT 1 bar GAS PRESSURE FOR 0.213 mm NOZZLE, NOP = 220 bar

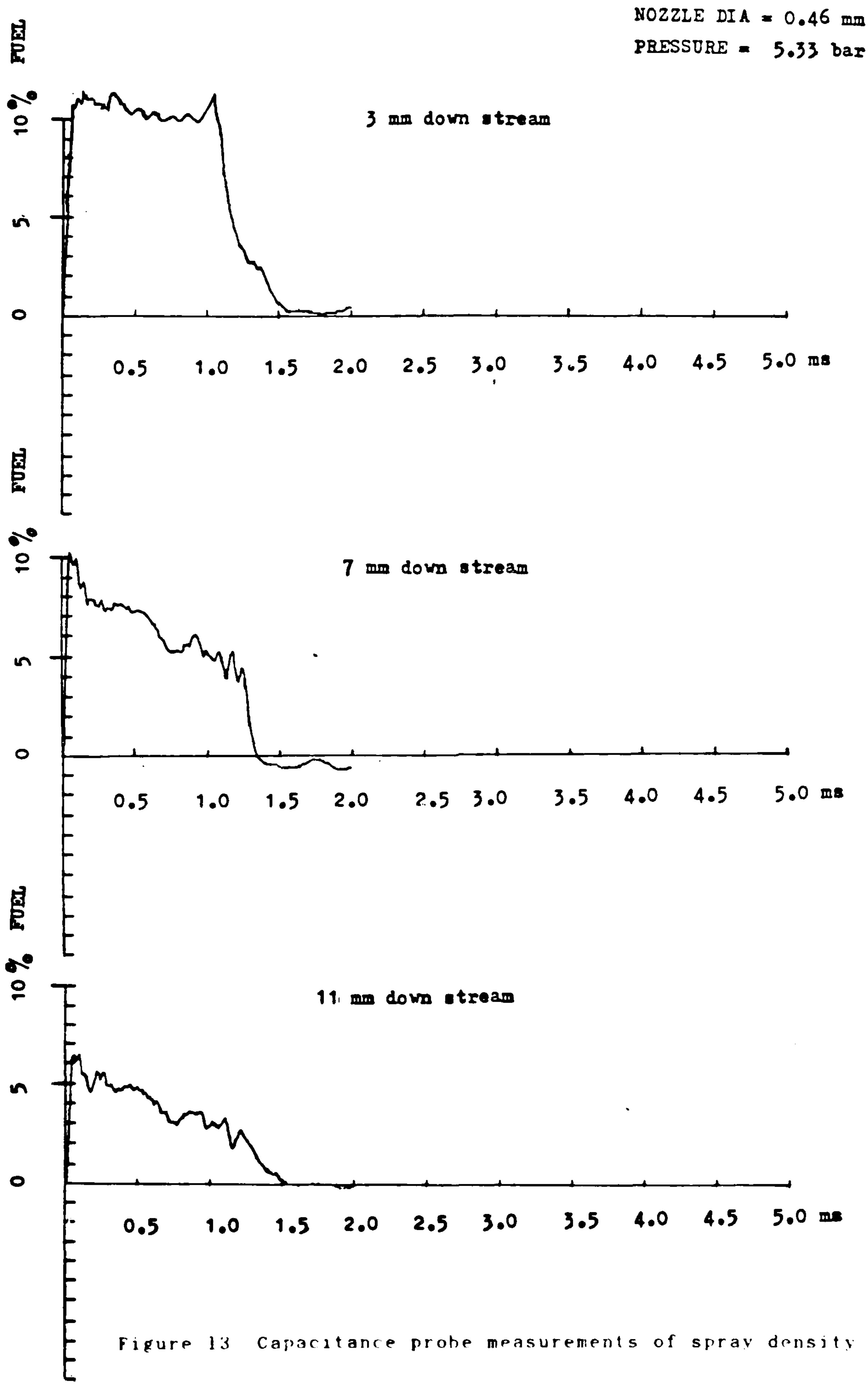
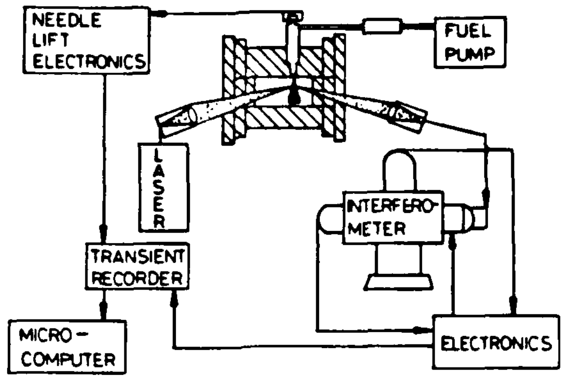


Figure 13 Capacitance probe measurements of spray density



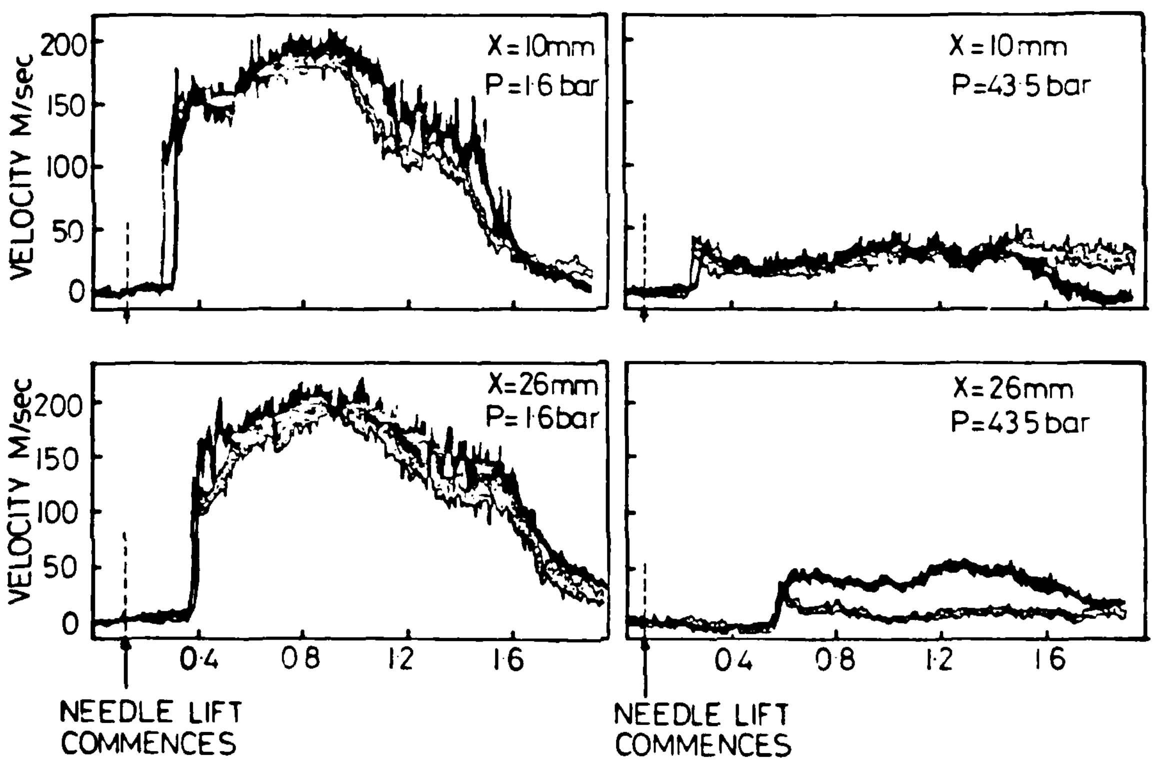


Figure 14. Single beam laser interferometer measurements of liquid phase velocity

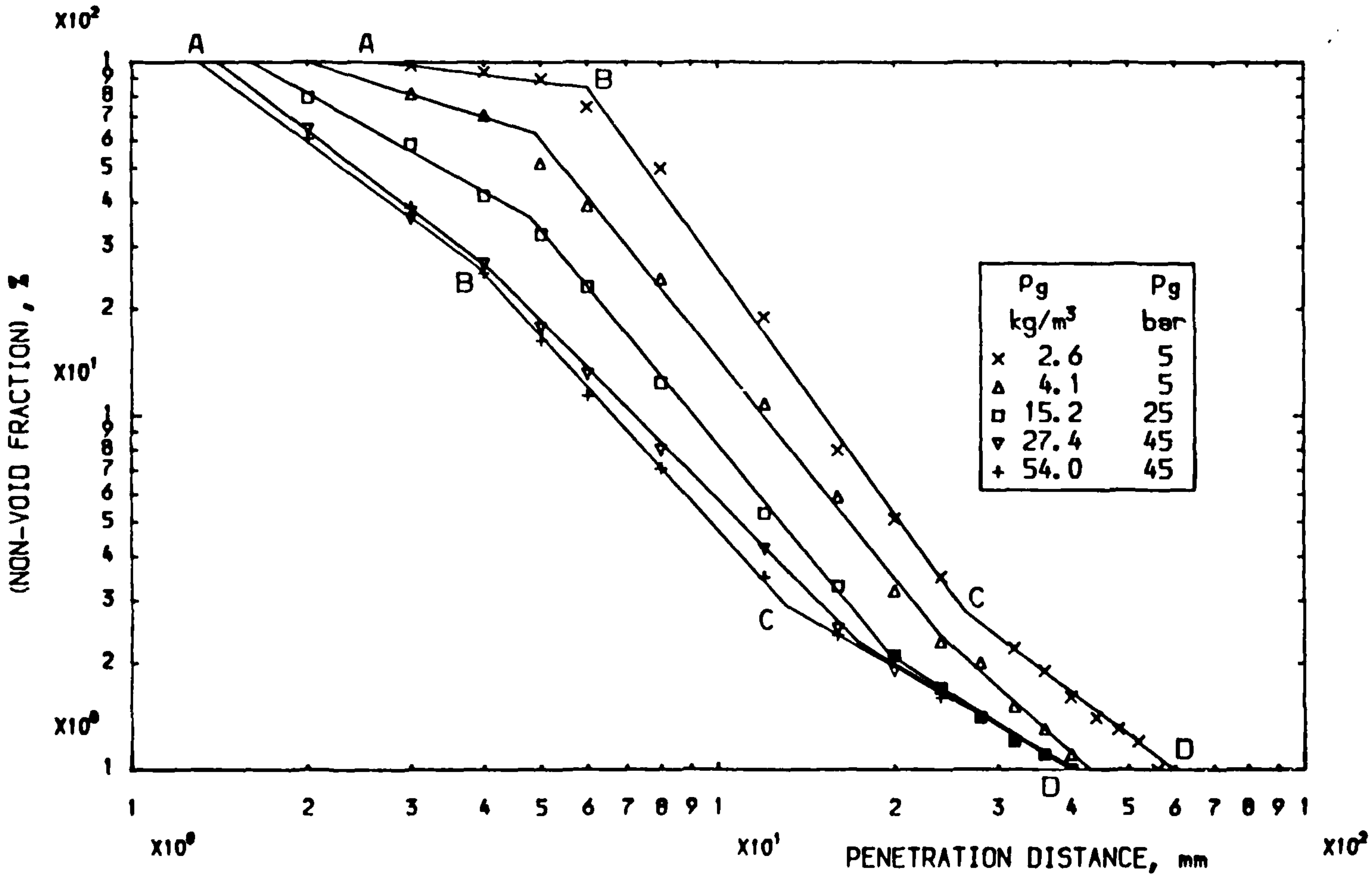


FIG. 15 EFFECT OF GAS DENSITY ON VOID FRACTION (LINEAR APPROXIMATION) FOR 0.213 mm NOZZLE

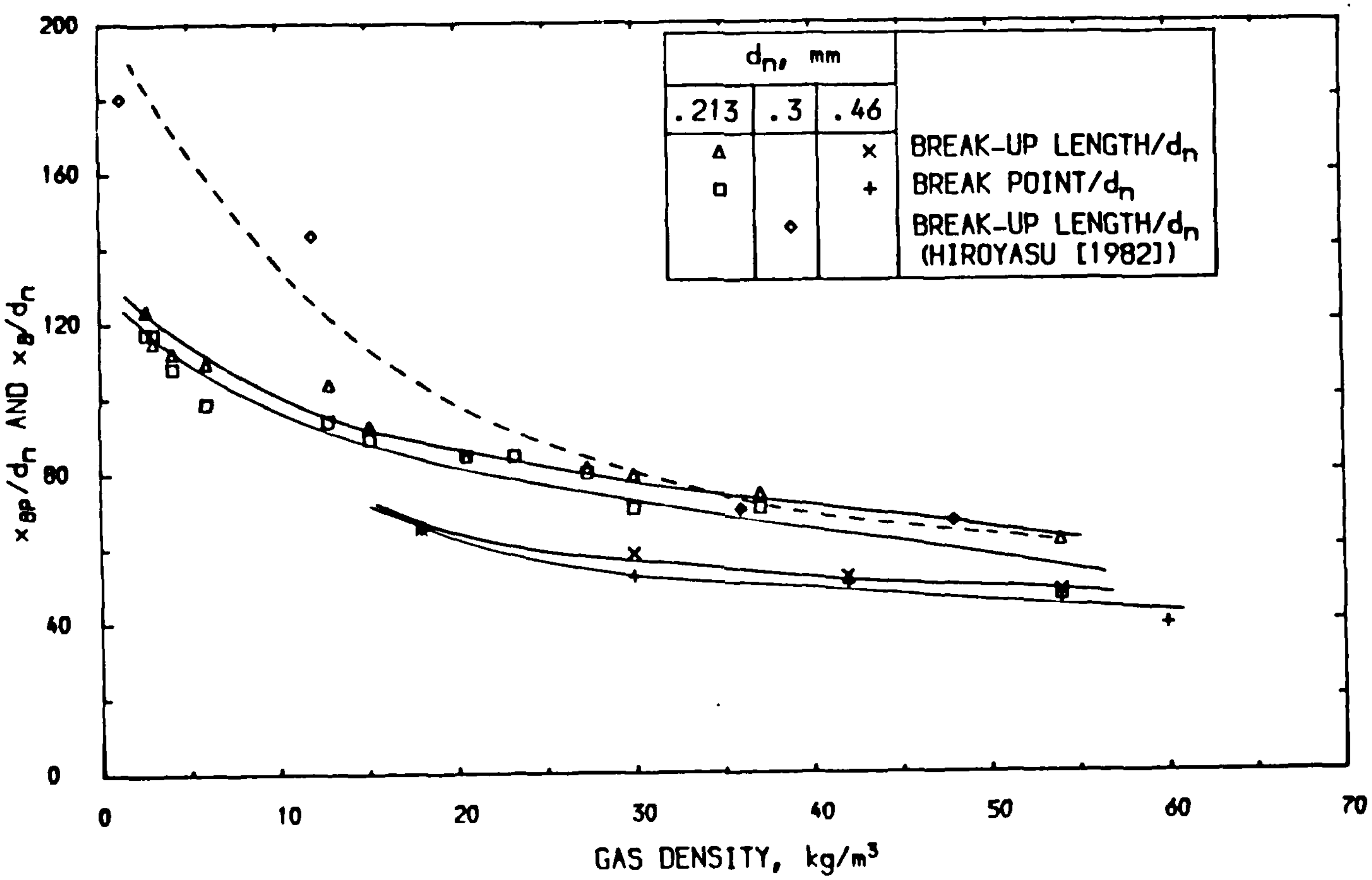


FIG. 16. EFFECT OF GAS DENSITY ON RATIOS OF BREAK-UP LENGTH AND BREAK POINT TO NOZZLE DIAMETER

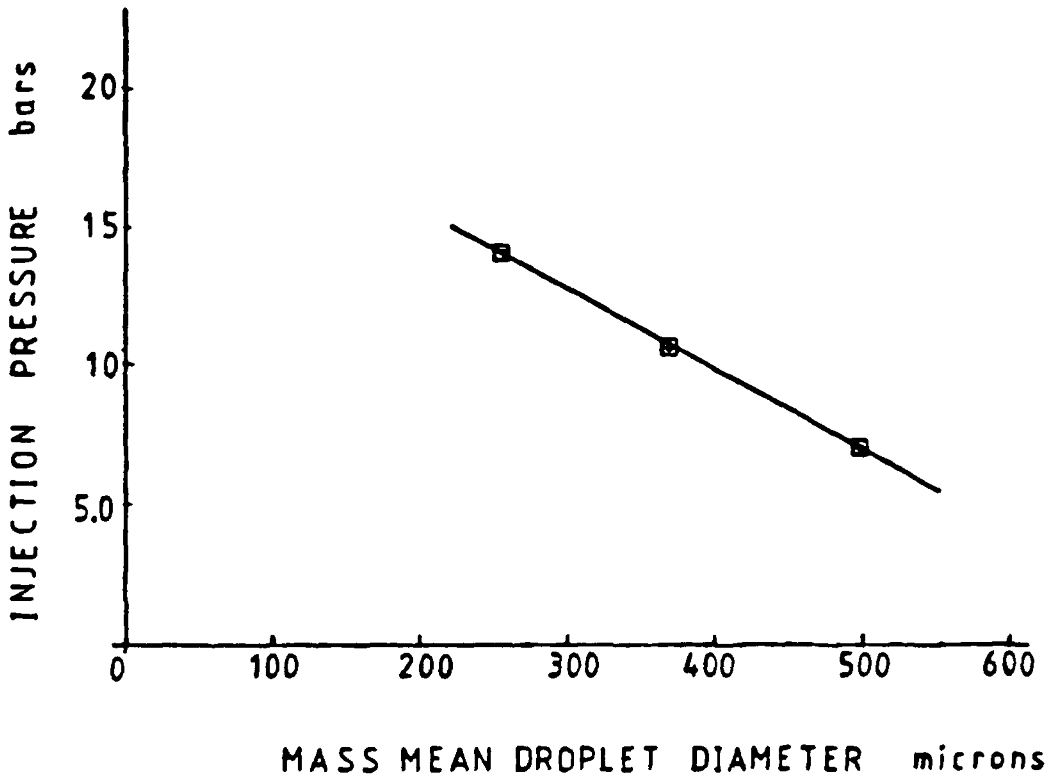


Figure 17. Effect of injection pressure on mean droplet diameter.

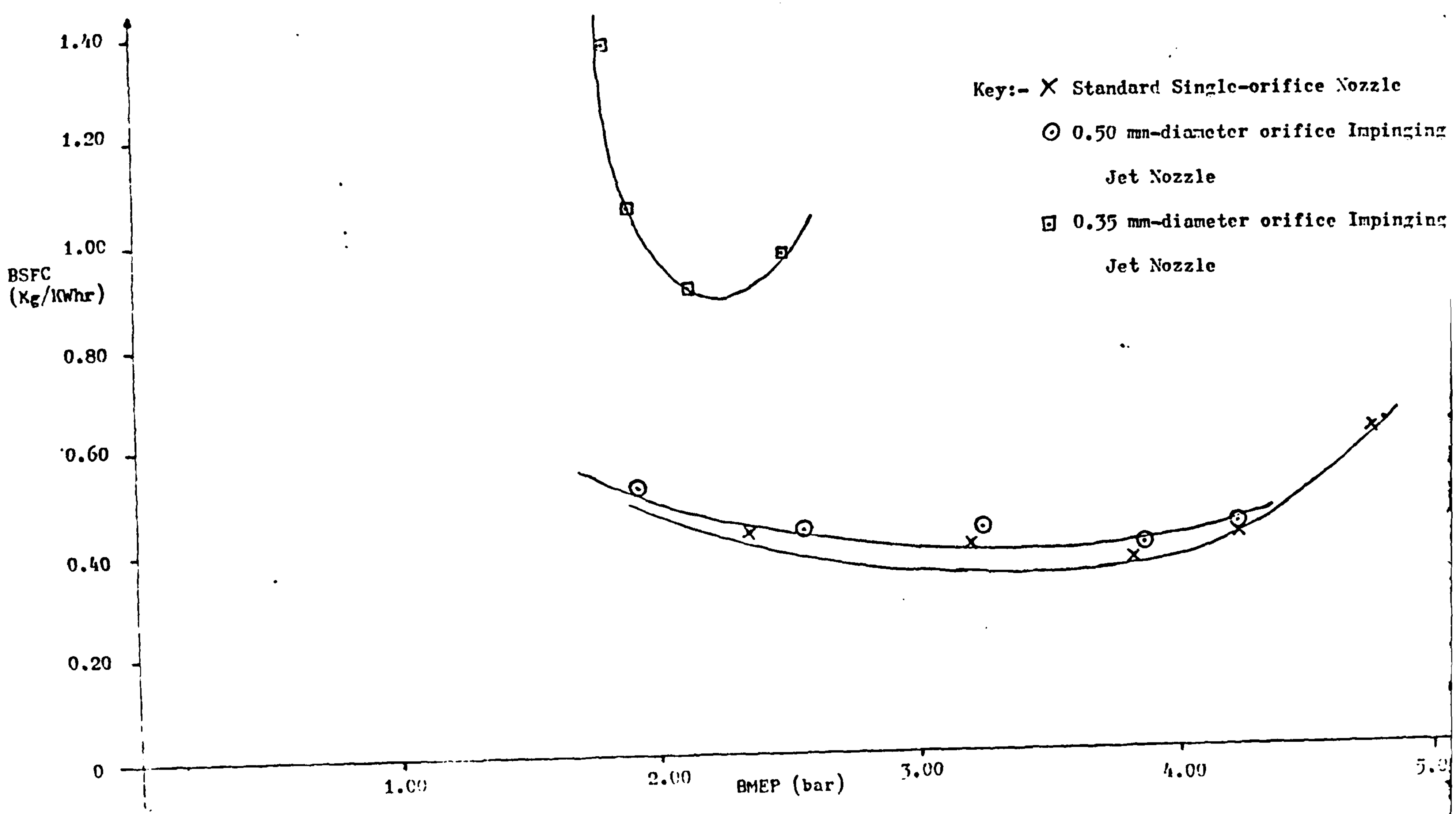


Figure 18 : Engine Performance Test Results -- BSFC plotted against BMEP at constant speed (1050 rpm)

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